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FINAL TECHNICAL REPORT FOR:

**ACCELERATION OF POSITRONS IN
SUPERNOVA SHOCKS**

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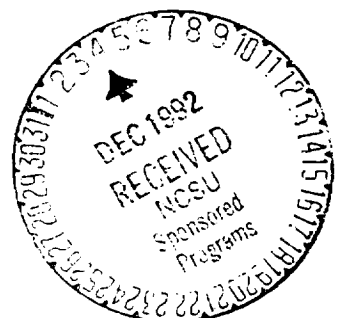
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SUMMARY OF PROJECT NAG 5-1131

During this project we investigated the acceleration of leptons (electrons and positrons) in collisionless shock waves. In particular, we were interested in how leptons are accelerated in the blast waves existing in the remnants of supernova explosions. Supernova remnants (SNRs) have long been considered as the most likely source of galactic cosmic rays but no definite connection between SNRs and the cosmic rays seen at earth can be made. The most convincing evidence that SNRs produce energetic particles is the fact that they are observed to be radio sources. The synchrotron radio emission is almost certainly produced by relativistic electrons (and/or positrons) and is direct evidence that the SNR blast wave produces energetic particles. Only by understanding lepton acceleration in shocks can the rich SNR data base be properly used to understand cosmic ray origins.

The favored mechanism for accelerating particles in shocks is Fermi acceleration whereby particles scatter back and forth across the shock and receive repeated energy boosts as they collide with the upstream and downstream plasma. This mechanism has received a great deal of study, however, virtually all of the theoretical work has been directed toward understanding ion acceleration. The study of lepton interactions with shocks is much more difficult to treat analytically (and computationally) and has not received as much work. Our project was directed at the neglected aspects of lepton acceleration.

We performed calculations using a Monte Carlo particle computer simulation which overcomes many of the problems which have prevented lepton studies in the past. We can treat thermal particle injection, transrelativistic effects, and the feedback of the accelerated particles on the shock structure in a direct way not possible with other current techniques. Below is a list of some of the important discoveries made during this project:

1. We showed that the efficiency of lepton acceleration depended critically on the lepton injection energy. If it is assumed that leptons have a diffusion coefficient similar to protons, thermal leptons will not be accelerated by the shock. Only when the lepton injection energy is many times the thermal energy, will significant numbers of leptons be accelerated. This comes about because the shock structure is modified and smoothed by protons, not leptons, due to their high mass and the smooth shock prevents low energy leptons from receiving strong energy boosts upon crossing the shock. We were able to quantify this effect and it is published in Ellison and Reynolds (1991b).
2. We showed that, even when injection effects are not important, that proton and lepton distribution functions produced by shocks are quite different in the critical energy range for producing the observed synchrotron emission. Until this result, it was universally assumed that ions and leptons would have similar spectra. We also showed that transrelativistic effects produced proton spectra that were not in agreement with standard results from radio observations, but that the lepton spectra were, in fact, consistent with observations (Ellison and Reynolds 1991b; Reynolds and Ellison 1992).
3. We performed simulations of relativistic shocks (shocks where the flow speed is a sizable fraction of the speed of light) and discovered some interesting effects. We first demonstrated the power of the Monte Carlo technique by determining

the shock jump conditions in relativistic shocks (Ellison and Reynolds 1991a). We were able to perform calculations including both protons and leptons that can not be done analytically allowing us to calculate the amount of electron heating in relativistic shocks not undergoing Fermi acceleration. We then proceeded to determine how relativistic shocks accelerate particles. We started with a test-particle calculation (Ellison, Jones, and Reynolds 1990) which allowed us to determine the acceleration time. From there we proceed to a full nonlinear calculation and found that nonlinear relativistic shocks treat protons and leptons even more differently than nonrelativistic shocks. The transrelativistic effects on the shock structure from the heavy ion component reduces the lepton acceleration to a tiny fraction of the ion acceleration. This effect is dramatic even if high energy leptons (many times thermal energy) are injected, and was totally unexpected. Our results have important consequences for astrophysical environments expected to harbor relativistic flows such as extra-galactic radio sources and accretion onto compact objects. This work was published in Ellison (1991a,b).

Below is a list of the published work associated with this project.

REFERENCES:

- "Diffusive Shock Acceleration of Decay Positrons in Supernovae," Ellison, D.C., Jones, F.C., and Ramaty, R., 1990, *Proc. 21st Int. Cosmic Ray Conf. (Adelaide)*, 4, 68.
- "First-Order Fermi Particle Acceleration at Relativistic Shocks," Ellison, D.C., Jones, F.C., and Reynolds, S.P., 1990, *Astrophys. J.*, 360, 702.
- "Cosmic Ray Sources and Cosmic Ray Acceleration," 1990, Rapporteur paper in *Proc. 21st Int. Cosmic Ray Conf. (Adelaide)*, 11, 133.
- "Modeling Fermi Acceleration at Parallel Shocks with Monte Carlo Methods," Ellison, D.C., 1991, *Adv. Space Res.*, 11, 265, Invited paper for XXVIII COSPAR Conf., The Hague, The Netherlands, July 1990.
- "A Determination of Relativistic Shock Jump Conditions Using Monte Carlo Techniques," Ellison, D.C., and Reynolds, S.P., 1991, *Astrophys. J.*, 378, 214.
- "The Physics of Collisionless Shocks," F.C. Jones and D.C. Ellison, 1991, *Space Sci. Rev.*, 58, 259, Invited review paper.
- "Fermi Particle Acceleration in Relativistic Shocks: Preliminary Nonlinear Results," Ellison, D.C., 1991a, in *Relativistic Hadrons in Cosmic Compact Objects*, eds. A.A. Zdziarski and M. Sikora, Springer-Verlag, p. 101.
- "Fermi Particle Acceleration in Relativistic Shocks: Spectra and Efficiencies from Modified Shocks," Ellison, D.C., 1991b, in *Astrophysical Aspects of the Most Energetic Cosmic Rays*, eds. M. Nagano and F. Takahara, World Scientific, p. 281.
- "Electron Acceleration in a Nonlinear Shock Model with Applications to Supernova Remnants," Ellison, D.C., and Reynolds, S.P., 1991, *Astrophys. J.*, 382, 242.

- "Radio Spectra of Supernova Remnants Modeled by Electron Acceleration in a Modified Shock," Reynolds, S.P., and Ellison, D.C., 1991, *Proc. 22nd Int. Cosmic Ray Conf. (Dublin)*, 2, 404.
- "Electron Acceleration in Tycho's and Kepler's Supernova Remnants: Spectral Evidence of Fermi Shock Acceleration," Reynolds, S.P., and Ellison, D.C., *Astrophys. J. Lett.*, 92, 399, 19L75.
- "Monte Carlo Simulation of Electron Acceleration in Modified Relativistic Shocks," Ellison, D.C., 1992, *Proc. Particle Acceleration in Cosmic Plasmas*, AIP Conf. Proc. No. 264, Eds., G.P. Zank and T.K. Gaisser, p. 331.
- "Electron Acceleration in the Galaxy: Observations and Theory," Reynolds, S.P., 1992, *Proc. Particle Acceleration in Cosmic Plasmas*, AIP Conf. Proc. No. 264, Eds., G.P. Zank and T.K. Gaisser, p. 409.